Simulations of Atmospheric Dynamics and Cloudiness in A Coastal Region

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LONG TERM GOALS

The goal of this project is to increase understanding of the modification of complex atmospheric dynamics and thermodynamics due to the interaction of the air, sea, and land in a coastal region. This increased understanding will improve the forecasting of coastal weather on a wide spectrum of spatial and temporal scales.

OBJECTIVES

Specific project objectives include: 1) investigating the structure and evolution of a low-level jet over the coastal waters as well as modification of the jet by thermal and topographic effects, stability and turbulence transfer, and cloud-driven processes; 2) investigating the main determinants of the development of local circulations, including land-sea breezes; 3) developing conceptual and operational models for improved prediction of fog and clouds over the coastal waters; and 4) conducting a comprehensive evaluation of mesoscale models in predicting weather in coastal regions. The project is supported by the Office of Naval Research, Marine Meteorology and Atmospheric Effects.

APPROACH

The proposed approach involved the use of selected atmospheric models and measurements from routine observations (surface stations, buoys), remote sensing instruments (wind profilers), and a special field program (Coastal Waves 96). Most previous modeling studies of weather phenomena on the U.S. west coast have focused on either idealized conditions or several-day cases. We have performed a numerical experiment using Mesoscale Model 5 (MM5) to simulate hourly atmospheric dynamics and thermodynamics in this region for all of June 1996. This model was utilized for short- and long-term numerical simulations of atmospheric processes over the U.S. California coast. The model grid encompassed the coastal area from north of Cape Mendocino to the Los Angeles basin. We also have developed a parameterization of turbulence kinetic energy and turbulence fluxes linked to the MM5 results (Kora• in et al. 1998a). We have also tested the Regional Atmospheric Modeling System (RAMS) with regards to its ability to predict land and sea breezes along the California coast with a horizontal resolution of 2 km on a nested grid. For a sensitivity study of the conceptual evolution of the offshore fog we used a high-resolution 1-D turbulence closure model.

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WORK COMPLETED

We performed a numerical experiment simulating hourly atmospheric dynamics over the U.S. California coast for all of June and July 1996 with high horizontal (9 km) and vertical (35 levels) resolution. The model domain was 900 km x 900 km x 15 km. Model simulation results were stored in hourly intervals. Model evaluation was reported in Kora• in (1998) and Kora• in et al. (1998b). Extended model evaluation for all of June 1996 was performed using data from four wind profilers, nine buoys located in the California coastal waters, and two land (shoreline) stations. On the basis of more than 18,000 simultaneous data and model results, we concluded that the hourly model results correlated closely with wind profiler data at different vertical levels, as well as with buoy and land-station data for the study period. The effect of the sea breeze in altering the persistent onshore flow in Monterey Bay was simulated with MM5 using a horizontal resolution of 3 km for the nested grid. We have also simulated a case study of land and sea breezes in Monterey Bay using the RAMS model with a horizontal resolution of 2 km for the nested grid. Many computer programs were created for numerical analysis as well graphical presentation of the model results, including animation.

RESULTS

The model evaluation and an analysis of the simulation results are fully described by Kora• in (1998). Here, we present a summary of the main results. The correlation coefficients between the measured and simulated wind speeds and directions were usually in the range of 0.5 to 0.9 with a relatively low bias. According to a spectral analysis of the hourly modeled and measured wind speeds for all of June 1996, the model was able to reproduce the diurnal periodicity which was evident in the measured data. The results from the model evaluation give confidence for the use of these simulation results to infer the average properties of atmospheric dynamics in the warm-season months along the U.S. California coastal waters and further offshore.

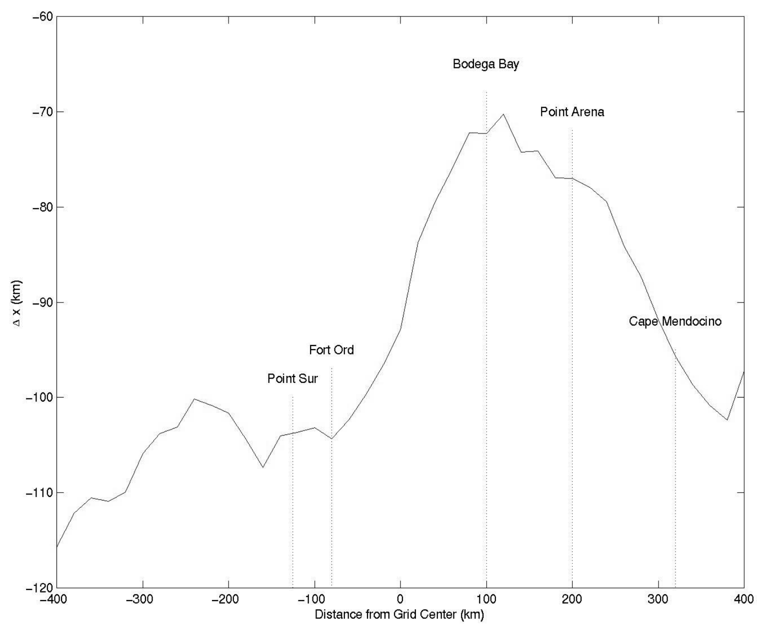

Figure 1: Distance from the coast (• x) in the offshore direction to which the topographic blocking is significant for points on the coastline. The x-axis is kilometers in the south-north direction from the model grid center.

A method of quantifying topographic blocking based on the fractional change of kinetic energy in the offshore direction has been presented. Assuming characteristic parameters of the California coast, for every increase of 1 ms^{-1} of the wind component that is perpendicular to the coastal mountains in the undisturbed upwind locations, the blocking influence will increase by about 30 km. Using the monthly-averaged simulated winds, the calculated blocking ranged from 70 km (northern part of the domain) to 110 km (southern part of the domain) (Fig. 1).

The model was able to reproduce the spatial variability of the MABL depth ¥¥ shallow in the proximity of the coast and deeper in the offshore direction. The decrease of the MABL depth is also influenced by the atmospheric stability in upwelling zones within the expansion fan areas. The greatest divergence is simulated in the proximity of the coast (50-100 km); it is caused mainly by the cross-coast, thermally-forced accelerated flow. The convergence zones are narrower than the divergence zones and extend approximately 30-40 km in the offshore direction. According to the simulation results, the downwind distance within the expansion fans in these areas appears to be greater than the calculated Rossby radius of deformation. Consequently, the Coriolis effect can enhance the westward extension of the expansion fans. It should be emphasized that the areas downwind of Cape Mendocino, Point Arena, and Point Sur are characterized by maximum winds within the MABL, minimum MABL depth, wind expansion fans, strongest flow supercriticality, and minimum Rossby radius of deformation. These distinct areas are confined within the region of the greatest estimated topographic blocking and strongest kinetic energy of the flow.

Kora• in et al. (1998c) simulated the sea-breeze's effect on the persistent onshore flow in Monterey Bay during 20-21 July 1996. They found that the daytime variability of the flow extends to about 50 km in both the offshore and onshore directions, while the nighttime variability is confined to a region 20-30 km offshore.

The full cycle of the land and sea breezes in Monterey Bay during 16-17 September 1987 has recently been simulated with the RAMS model. The model has been evaluated using radiosonde and lidar data and was able to reproduce the main structure of land and sea breezes, including the onset and characteristic depth. In order to visualize complex flows during the land and sea breezes, we used the Lagrangian random particle dispersion model (Kora• in et al. 1998d).   We set up four emission sources along the Monterey Bay coastline and used the simulated atmospheric fields as input to the particle model. The results indicate significant daytime inland penetration of the sea breeze, facilitated by the divergence fields associated with upslope flows (Fig. 2). During the nighttime, the offshore flows are enhanced by drainage flows (Fig. 3).

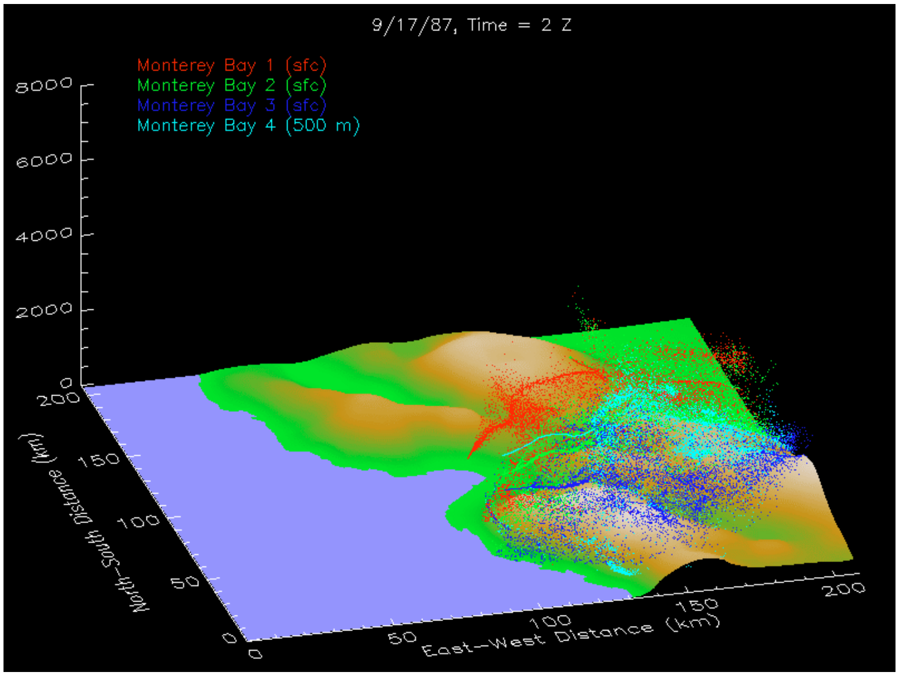

Figure 2: Visualization of the airflows simulated by RAMS using a Lagrangian Random Particle Dispersion Model as applied to four sources on the shoreline after a developed sea breeze condition in Monterey Bay on 16 September 1987 at 1800 LST.

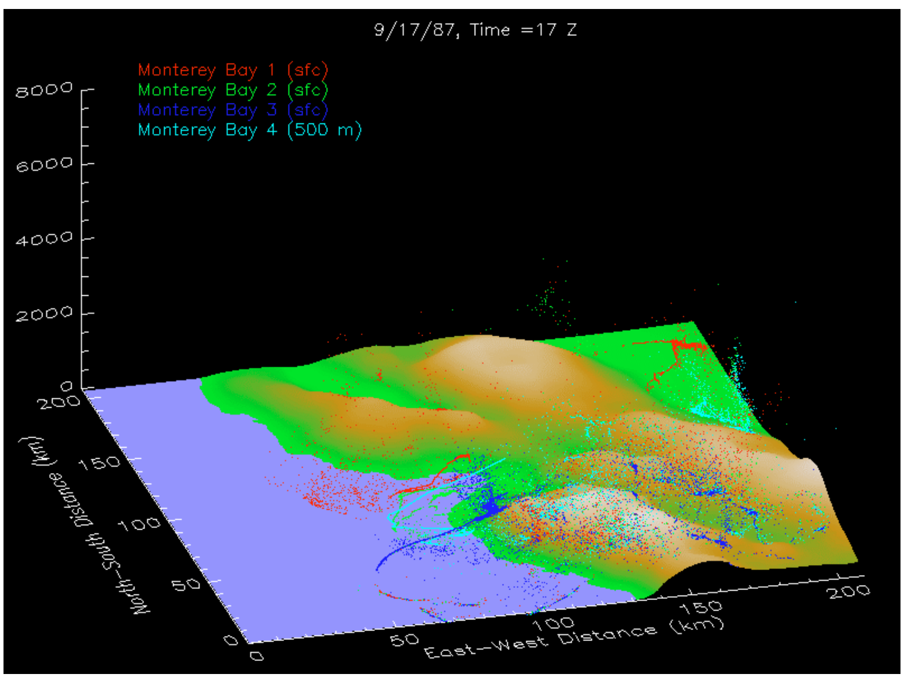

Figure 3: Visualization of the airflows simulated by RAMS using a Lagrangian Random Particle Dispersion Model as applied to four sources on the shoreline after a developed offshore flow condition in Monterey Bay on 17 September 1987 at 0900 LST.

Leipper and Kora• in (1998) investigated the importance of occasional hot spell events on different coastal weather phenomena, particularly the formation and evolution of coastal fog and stratus clouds. They performed numerical simulations using idealized radiosonde data as input to a 1-D higher-order closure model. The fog was first simulated in the moist and cool shallow marine layer, and its evolution was significantly determined by radiative processes and the generation of turbulence within the fog layer. The sensitivity study has shown the importance of vertical resolution in properly resolving the radiative effects and influence of the sea-surface temperature and surface waves, as well as the properties of the near-surface inversion.

IMPACT

The results of this study improves the predictability of wind, turbulence, clouds, fog, and stable internal boundary layers in coastal areas. This will aid in decision making and in the performance of low-level airborne and sea-based naval operations. The results may be applied to other coastal areas worldwide.

TRANSITIONS

NPS (Dr. Le Ly) is currently testing the possibility of using MM5 wind fields developed by this study to drive the Princeton ocean model. Based on the experience from this study, we simulated a strong wind (bora) case in the Adriatic Sea. The results have been used by our collaborators from Croatia (the Oceanographic Institute in Split) to drive an ocean model to investigate a vortex observed in the northern Adriatic. We have started preliminary plans for a joint study with Scripps (Dr. Clive Dorman) focusing on the effects of dynamical fields on the evolution of cloudiness along the coast. This study will use our developed monthly simulations. The University of Uppsala in Sweden (Dr. Michael Tjernström) is planning to use our month-long simulation results to study the transport and dispersion of atmospheric pollutants on the U.S. west coast. We are also planning to compare navy (COAMPS) and public-type (MM5) models, as well as to enhance forecasting techniques at the NWS offices through the use of numerical simulations.

RELATED PROJECTS

We are collaborating with Drs. Wendell Nuss and Le Ly (NPS, Monterey), Dr. Clive Dorman and Dr. David P. Rogers (Scripps, San Diego), and Dr. Michael Tjernström (Uppsala University, Sweden), all of whom have ONR funding. We are collaborating with Dr. Dale Leipper on a NWS project to operationally test his system for forecasting fog at the Monterey Bay airport. The P.I. for this project, Dr. Kora• in, has another ONR funded project (N00014-96-1-1235), which focuses on turbulence transfer over inhomogeneous surfaces and was also applied to the evolution of marine clouds. The results from these two studies motivated the development of a proposal to DOD-ONR (Drs. S. Chai and D. Kora• in, co P.I.s) focusing on modeling the dispersion of vapor and aerosol particulates in complex terrain, which has been approved.

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